MEDDELANDEN FRÅN UPPSALA UNIVERSITETS GEOGRAFISKA INSTITUTION
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THE LOWER ÅNGERMANÄLVEN

A STUDY OF FLUVIAL MORPHOLOGY AND PROCESSES

BY

LENNART ARNBORG

UPPSALA 1959

Almqvist & Wiksells Boktryckeri AB

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A STUDY OF FLUVIAL MORPHOLOGY AND PROCESSES

Inaugural Dissertation

BY

LENNART ARNBORG
Fil. lic., Västg.

By due permission of the Faculty of Science of the University of Uppsala, to be publicly discussed in the lecture hall of the Institute of Geography, December 5, 1959, at 10 a.m., for the degree of Doctor of Philosophy.

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The funnel-shaped underwater delta of the Ångermanälv. Discharge ~400 m^3/sec. Surface = −0.32 m above sea-level. Photo: The Map Department of the Ordnance Survey, 1st September, 1956, at 10.26 a.m. Published with the permission of the Defence Council granted on 16th November, 1959.

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A Study of Fluvial Morphology and Processes

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Investigations of a fluvio-morphological kind were carried out by the author in the lower part of the Ångermanälven within the 45-kilometre stretch of river from Forsmo to Nyland and also within the recent delta area at Nyland. The main investigations refer to the delta development during the period 1947–1958. During this period considerable controls of the river discharge were gradually carried out in connection with the utilization of the water-power for the production of electrical energy. The problems were concentrated around the consequent effect of the controls, primarily as regards bed morphology, sediment, vegetation, current conditions and transport of material. As the investigations were partly carried on by the use of new methods, of which the frogman technique for direct observations of the beds was probably the most important, new objects of investigation could be studied and analysed for the illustration of the activity of different fluvial processes.

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The present dissertation is based on investigations published in the following papers:

I. The Delta of Ångermanälven. — Geografiska Annaler XXX, pp. 673–690. Stockholm 1948.

II. Erosion Forms and Processes on the Bottom of the River Ångermanälven. — Geografiska Annaler XXXIX, pp. 32–47. Stockholm 1957.

III. The Lower Part of the River Ångermanälven. Part 1. Report on the effect of water control on the forms of erosion and fluvial processes in certain salmon-fishing stretches. — Reprint from Publications from the Geographical Institute, University of Uppsala, Physical Geography No. 1, pp. 181–236. Appendix: 108 maps and diagrams. Uppsala 1958.

IV. Nedre Ångermanälven, Del II. Vattenregleringarnas inverkan på morfologi och fluviala processer, särskilt inom det recenta deltaområdet 1947–1958. — Avhandlingar från Geografiska Institutionen vid Uppsala Universitet. Naturgeografi Nr 2, pp. 1–180. Appendix: 96 maps and diagrams. Uppsala 1959.

PAPER I

In this report an account is given of results of investigations within the delta area during 1947 at a discharge of between 300 and 500 m^3/sec., and in 1948 at 1600–1700 m^3/sec. Erosion and sedimentation areas are reported according to a comparative analysis of soundings from 1946 and 1948. Compared with later investigations, it may in general be pointed out that the accumulation processes have continued within the areas which were marked as being of deposition type. The erosion has, however, in general not proceeded in the fashion which was indicated by the erosion marking on the map (Fig. 5), but as the sounding values cannot be pressed too far, no general conclusions can be drawn. The most important feature is, however, that the erosion at Nyland quay continued and was even considerably intensified around the beginning of the 1950s.

In these investigations the so-called sand-trap was introduced for direct measurement of ripple transport. In the first version there were, however, no built-in photocells for recording the velocity of transport, wave-length and wave-height of ripples. The apparatus was, however, so constructed that direct samples could be taken of demonstrable bed-load material. The grain-size analyses carried out on ripple material during general transport then turned out to exhibit a marked limit at the grain size of 0.25 mm. Later diving investigations and sample-taking have shown that material finer than this particle fraction is practically non-existent within the area, when general transport of tongue-shaped ripples occurs with a wave-length of at least 20 cm and a wave-height of at least 3–5 cm. This limit, which, on account of the analysing procedure, cannot be determined in more detail, shows, however, that the limit against finer material for bed-load material in ripples is very sharp.

PAPER II

This report reproduces the first results which were forthcoming after it was possible for direct observations of the bed to take place by means of frogman diving. As the river bed partly consisted of well-consolidated cohesive material, it was possible to carry out a classification of the different erosion phases and morphological elements which such a sub-aquatic sediment may display. Other forms described are: residual beds of friction material, detail forms in unconsolidated cohesive material and the aquatic vegetation. These things are discussed at greater length in Papers III and IV.

The erosion of consolidated cohesive material

It is possible systematically to arrange the different phases of erosion to which the cohesive silty sediment is exposed below the surface of the water in 6 groups:

1. Erosion of single particles and aggregates of particles by (a) relatively clear water, (b) silty corrading water.
2. Corrasion of cohesive material by bed-load transport.
3. Evorsion by pebbles and stones forming pot-holes.
4. Erosion caused by the existence of cracks in the material.
5. Erosion by peeling of isolated horizontal surface layers.
6. Erosion associated with animal life in the sediment.

Of these six processes of erosion, corrasion is of the greatest importance. It may lead to the formation of channels, ravines (Fig. 8) and canyons with perpendicular walls, several metres in height.

PAPER III

This paper reports a summary of a study in applied geomorphology commissioned by the Mellanbygdens Vattendomstol (Water Court), Östersund.

The report contains photographs and maps of fluvio-morphological phenomena within certain parts of the stretch of river from Forsmo to Nyland. There are, *inter alia*, reproductions of several of the bed shapes formed through mechanical destruction by ice and also different types of bed of an erosion, transport and accumulation character, both for cohesive sediment of different degrees of consolidation and for frictional sediment of different grain sizes. A number of maps illustrate whether net erosion or net accumulation has occurred in different areas during a certain period of time.

The investigations illustrate the effect of annual and periodical controls and have made possible the following comparison.

The annual control (the annual discharge under controlled conditions) has the following results for the part of the river examined, compared with the uncontrolled conditions:

(a) During the summer there is a reduction in the lateral and vertical erosion and in the bed load.

(b) The deposition of fine material increases within certain parts and locally also that of coarser material.

(c) During the winter the mobility of the bed increases.

(d) The vegetation increases.

The periodic control (short-term fluctuations in the discharge) results in the following changes:

(a) There is an increase in the tendency to direct ice erosion of the bed and shore. (Type V. Granvåg, Rämsle Island, Björkäng and Figs. 18, 21, 22, 23, 194, 197, 204, 210, 211, 219, 220 and 221.)

(b) The higher mean discharge and also the greater variation of the discharge cause an increased and more variable velocity of flow. On

account of this fact and also on account of the variations of the water stages the ice cover may be retarded or not at all developed within certain parts of the river. For these reasons the conditions for the formation of frazil ice and ice block dams increase. (Figs. 104, 105, 189, 198 and 199.)

(c) There is an increased tendency to ice jamming of cross-sections, with consequent rise in the water level. This could lead to subsidence of the bank. (Björkäng type, downstream of Rödskägg and Ö. Granvåg, Fig. 23 and Plates III and IV.)

(d) There might be a displacement of the main stream of the river owing to frazil ice below the ice cover, which may result in both lateral and vertical erosion within the regions where such erosion will not normally occur during ice-free periods. (Type Käll, Fig. 104.)

(e) The ground water table in the river scarps may be unable to follow the rapid fluctuations of the river level during periodic control, as a result of which an overpressure may be formed by the ground water table in the sand strata; this gives rise to transport of sand and the formation of small ravine-like structures. (Fig. 228.)

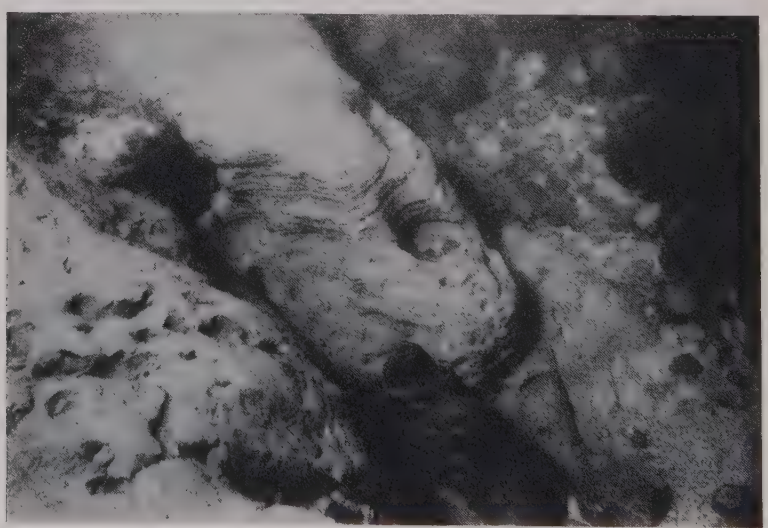

Fig. 13. A form of erosion resembling that occurring in rock is also found in the subaquatic fiord sediment. Transported pebbles and sand have excavated pot-holes and subaquatic ravines and channels. Photo L. A., 23rd July, 1956.

PAPER IV

This report deals primarily with the development of the recent delta area during the period 1947–1958, but also gives certain points of view on the stretch of river between Forsmo and Nyland and short accounts of the size, climate, bed-rock and soil species of the drainage basin.

The investigations resulted, *inter alia*, in a comparison of different forms in the river bed, based upon direct observations by the author wearing a frogman's outfit.

An account is also given in the report of the development of the delta area according to an analysis of old maps, aerial photographs and sounding charts. Also illustrated are the velocity of the water and the discharge during the period of investigation, the changes in the bed in connection with the carrying out of the controls, the stratigraphy of the delta, the transport of sediment in the water and the contact of the river water with the salt water in the fjord at the delta's distal slope.

The investigations of the water flow show, *inter alia*, that between 50 and 65% of the total discharge on the delta runs in a channel 100–150 metres wide and about 10 metres deep immediately off Nyland quay.

During the period of investigation the surface material of the delta changed from purely sandy to silty material in extensive areas.

The transport of sediment in the water, which was calculated by means of water sampling for the period 1951–1957, shows an average of about 100,000 metric tons of suspended mineral silt per year. For the year 1956, when investigations were also made of the water's content of substances in solution, the following values were obtained:

Total Transport in 1956

Suspended inorganic particles, metric tons	Substances in solution, metric tons	
	Inorganic salts	Organic substance
100,000	360,000	110,000

As this year no bed load occurred within the delta area, the total transport by the river consisted of 570,000 metric tons of material. Of the salts in solution, however, about 120,000 metric tons came from the atmosphere, and therefore the total denudation within the river basin, 32,000 km² in area, may be considered to be of the order of magnitude of 14 metric tons per km².

The main investigations, which concern the effect of the annual and periodic controls of the river discharge, have made possible the following comparison:

The annual controls result for the delta area in:

(a) a reduction in the high-water flow-rates and the high water velocities. On the other hand, no appreciable change took place in the percentage distribution of the discharge in different cross-sections during the period of investigation. (See Fig. 55.)

(b) a reduction in the mobility of the bed, which resulted both in reduced erosion and reduced bed-load transport. At a discharge < 1000 m³/sec. no bed-load transport occurs in the delta area on the whole.

(c) the substitution of perennial deposition of the stagnation sediment type for the earlier annual deposition of the "winter fur" type within most areas except the course of the main current. For the whole region the increase in the fine sediment cover, compared with uncontrolled conditions, may be estimated as on an average 5 mm per year. As the investigated area of the delta can be given as 2.5 km², this means that about 15,000–20,000 metric tons of fine sediment remain within the delta area, i.e. about 15–20 % of the river's total transport of inorganic silt. Under uncontrolled conditions this would be transported past the delta's distal slope.

(d) an increase in the rate of immigration of vegetation and an opportunity for it to spread out in all areas with a water depth of less than 1½–2 m, on a smaller scale also down to a depth of about 3 m. (The earlier mobility of the bed prevented such a development.)

(e) the cessation, for the most part, of the development of new shoals of the sandbank type, as bed load does not occur.

(f) a delay in the erosion of the deep channel under the left-hand part of the Hammar bridge and in a more rapid division of the delta area into a number of river branches than under uncontrolled conditions.

(g) the fact that the delta's distal slope, which before the controls was moved forward 4–8 m per year through the deposition of about 100,000 metric tons of sand and fine gravel, no longer displays any appreciable advance, as only deposition of suspended load takes place.

(h) the fact that the salt-water front at the distal slope is not pressed down to the same depth as at uncontrolled high-water. (Figs. 60, 61 and 62.)

The periodic controls result for the delta area in:

(a) the fact that fluctuations in the water velocity occurred with about 3–5 hours' time displacement in relation to the tapping values at Forsmo and Hjälta. The variations in the discharge during the period of investigation have, however, not resulted in any morphological changes in the subaquatic delta plane being observed up to now.

(b) the discharge variations causing displacements of the salt-water front at the distal slope. The salt water, however, does not force its way up in the delta area, at least not at a minimum discharge around 100 m^3/sec.

The purely sub-aquatic delta plane, which has been typical of the mouth of the Ångermanälven for the last 200–300 years, will change into a delta area with several river arms and with tree-clad islands and islets. This development is being accelerated by the present controls, but they have not been able radically to influence the natural development, the tendency of which has been illustrated by means of maps for earlier centuries and by direct observations in recent years.

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Lennart Arnborg

Uppsala, September 1, 1959

The white-flowered *Ranunculus peltatus* colonizes rapidly along the shores and in the region of the mid-stream banks, where the depth of the water is 0.6–2.0 metres. It has its optimal growth conditions at places where the water is about 1.5 metres deep and where the bottom consists of sand which has been stabilized and covered by a thin fine-grained sediment. It prefers a velocity of about 0.3 m/sec., but can stand more rapid currents. The photograph was taken about 20 metres from the shore line in the upper part of Kläpp fishing grounds. Photo Lennart Arnborg, 26th July, 1957.

Sw. kr. 5.—